Forecast the ocean's variability

The IPCC and policymakers need realistic regional projections of how the seas will respond to climate change in coming decades, write Daniela Schmidt and Philip Boyd.

The ocean modulates Earth's climate and provides us with food, coastal protection, clean seawater and the oxygen we breathe.

Only in the IPCC's latest 5th Assessment cycle[1,2] in year 2014 did the oceans have dedicated chapters. Now the IPCC is preparing a special interdisciplinary report on the ocean and cryosphere across all three working groups (alongside two others on the impacts of 1.5°C global warming and climate change and terrestrial systems)**.** In December a group of scientists will decide what to include in the ocean and cryosphere report, which will be published in 2019.

Offering robust projections that can be translated into practical policy is central. The report must link to the United Nations' Sustainable Development Goals (SDGs). For example, Goal 14 tasks governments to "sustainably manage and protect marine and coastal ecosystems from land-based pollution, as well as address the impacts of ocean acidification". The report must help marine managers and policymakers make decisions 'here and now'.

The IPCC needs to shift its approach, to offer short term climate change projections as well as longer term ones and to acknowledge the variable nature of the oceans not just global average trends. The report must include: forecasts of how fluctuations and shifts in surface temperatures and pH are driven by both natural and anthropogenic climate change**;** near-term predictions of extreme conditions such as marine heat waves on regional scales; and the biological mechanisms that underpin how key organisms and hence important ecological systems respond to climate change.

All this will take the IPCC out of its comfort zone. Decadal projections and regional foci will represent greater uncertainties and unknowns but at the same time provide frameworks to enable future marine planning. But such information along with calibrated uncertainty estimates are necessary to safeguard our seas.

Noisy waters

The impacts of climate change on the oceans are usually depicted using graphs. Lines represent projections of long-term globally-averaged quantities like relentless rises in mean sea surface temperature or acidification to the century's end. But the real ocean is noisy (Figure 1). It encounters fast and slow as well as local, regional and global variations in its conditions simultaneously.

The long term average state of the ocean is important to quantify – eventually the influence of anthropogenic climate change on the ocean will be larger than ongoing natural ocean variability[3] in a transition known as the 'Emergence'. But we are not there yet. The present oceanic signature of anthropogenic climate change is still comparable in its size and difficult to disentangle from natural and regional climate variability such as the El Niño–Southern Oscillation (cycles in winds and sea surface temperatures over the tropical east Pacific). The

Emergence will happen at different times in different places, for example the tropics are already recording extreme temperatures while the Emergence is several decades away in the mid latitudes[4].

Natural climate variability can offset or amplify climate change trends temporarily. For example, an apparent slowing or 'hiatus' in global average temperature rise between 1998 and 2012[5] led some critics to suggest anthropogenic climate change was less of an issue. Natural variability also reflects more extreme conditions, such as the currently strong El Niño (Figure 1)**.**

Anthropogenically-mediated increases in the frequency, severity and duration of extreme conditions[6] will have disproportionate adverse effects on marine ecosystems[7] . For example, in 2011 the west coast of Australia encountered sea surface temperatures 2-4°C warmer than average for 10 weeks. Its kelp forest, usually 800km long, shrank by 100km and lost 43% of its cover[7].

All these noisy fluctuations send a confusing message to marine resource managers, policy makers and the public. It makes management decisions about how best to adapt to climate change difficult, and short term forecasts more unreliable.

Local actions

Long-distance connections between regional climate patterns confuse local marine measures and predictions as oceanic and atmospheric processes are inherently linked.

Policymakers and marine managers need to know more about this variability and its impacts. Regional and local scales are most pertinent to managing marine resources. There will be hotspots of change, such as sites of marine heat waves[7] or places where regional warming exceeds the global average such the western Antarctic Peninsula. Yet the resolution and boundary conditions of global circulation models prevent better representation of changes in coastal regions. Regional projections from global climate models rarely agree and they exclude other human stressors such as fishing pressure and pollution.

The IPCC report needs to tease apart how combinations of global, regional and local anthropogenic stressors will increase pressures on marine ecosystems and services in particular places. This allows local management to buy time to mitigate the combined effects of multi-stressors. For example, managing the runoff of sediment, nutrients and contaminants into coastal waters near the Great Barrier Reef[8] gives corals respite from the crown-of-thorns starfish outbreaks that devastate them and add to the regular stress of bleaching (expelling algae under warmer conditions) during El Niño events.

Developing regional and local marine policies requires better understanding of governance mechanisms, management and trade practices too. The IPCC report should include examples of using local know-how to underpin policies. The focus is still too much on the physical signal. The IPCC report should include illustrative examples from Working Groups 2 and 3 of using home-grown knowledge to underpin policies, such as the local mitigation solution from the Great Barrier Reef. For the report to provide useful information for action, interdisciplinary studies including the legal and economic frameworks that support regional social and ecological resilience need to be conducted.

Set the scene

Another challenge for ocean scientists is to describe how marine life forms in diverse ecosystems will respond to the complex matrix of anthropogenic change[9]. Beyond snapshots of how a few species within coastal foodwebs react to more acidic or warmer conditions, biologists don't fully understand the cumulative responses of the key components that make up ecosystems, such as the productivity of fisheries to a changing climate.

Organisms may react in a non-linear way[1]. If a species is already at its temperature limit, any additional warming will have lethal consequences while a cooling would improve fitness. For example, many species of plankton in the tropical ocean are thought to be close their upper thermal limits[9].

Experiments need to reflect the wider range of changes to local ocean conditions that will occur over year to decades. And consider how extremes and fluctuating conditions affect physiologies. For example, by adding to anthropogenic warming, El Niño events may cause increased mortality for certain species in the Pacific; whereas the cooler La Niña phase of the cycle would offer respite. How these processes balance out, if the periods of relief are long enough to allow recovery, and which species will be most affected are all open questions. This uncertainty is fundamental to our ability to predict the societal impacts of these ecological changes.

Places where warming is now above the global average are natural laboratories[10]. They include treasured marine sanctuaries such as the Galapagos Islands and areas where humans rely heavily on ocean resources, such as South-eastern Asia and western Africa[10]. Environmental impact assessments in such laboratories have revealed that some ecological changes, such as the above described kelp losses, are irreversible even if the physical environment returns to mean conditions[7]. Some of these irreversible changes associated with heat waves result from migration of warmer water species into colder water habitats replacing endemic species which lived in these regions with unknown biological/physiological consequences. Extreme events therefore can push ecosystems past tipping points.

Describing the oceans variability will thus make sure the IPCC report builds a bridge to the SDGs and must be reflected in the choices made in December's meeting of ocean experts.

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Figure 1: Climate variability and the time-dependent nature of climate change[3],[11], on scales relevant to resource management and policy decisions. Climate change will result in the Emergence[3].

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